United States Department of the Interior
FISH AND WILDLIFE SERVICE
Mauna Loa Field Station
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May 21, 1985

Mr. Minabu Tagomori
Chief, Division of Water and Land Development
Department of Land and Natural Resources
P.O. Box 373
Honolulu, HI 96802

Dear Mr. Tagomori:

In view of the current controversies in the Puna area with regard to proposed geothermal development and biomass woodchipping, our office has taken time to summarize the information gathered during our Forest Bird Survey prior to the publication of our final reports. Enclosed is a copy of that report including all the attachments with the exception of the general vegetation map. I previously gave a copy of the colored map to Joe Kubacki and Dean Nakano when I met with them in April.

If it would be useful, I would be glad to meet with you to discuss this information in greater detail.

Please contact me if I can be of further help.

Sincerely,

James D. Jacobi

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Botanist

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SUMMARY OF THE BIOLOGICAL INFORMATION COLLECTED DURING THE U.S. FISH AND WILDLIFE SERVICE'S HAWAI'I FOREST BIRD SURVEY IN THE PUNA STUDY AREA ON THE ISLAND OF HAWAI'I

Prepared by

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INTRODUCTION

This report summarizes the data collected during the U.S. Fish and Wildlife Service's Hawai'i Forest Bird Survey (HFBS) in the Puna District on the island of Hawai'i, focusing on the lands owned by the James Campbell Estate and the State of Hawai'i in the Puna Forest Reserve and Wao Kele 'O Puna State Natural Area Reserve. The primary objective of the HFBS was to determine the current distribution, abundance, and status of the endangered native forest birds and their habitats on all of the major Hawaiian islands. Detailed information was also collected on the distribution of other native and non-native forest bird species, native plant species, and on introduced species of both plants and animals. Field work was conducted in the Puna area during the summer of 1979.

METHODS

Sampling Strategy

Field sampling during the HFBS was conducted along a series of transect trails established through each study area. Transects were spaced 3.2 km (2 mi) apart on the island of Hawai'i, and were located so they would generally run perpendicular to elevational contours (Fig. 1). Ten transects (#33-42) were established in the Puna study area (Fig. 2), which included the forested areas from the east side of Hawai'i Volcanoes National Park to above Pahoa, approximately between the elevations of 300 - 1050 m (1000 - 3500 ft).

Sampling points, called stations, were located at 134 m (440 ft) intervals along each transect. The stations were used as the primary locations for censusing all bird species and for describing the structure and composition of the plant communities. Additional incidental information was recorded for bird and plant species when traveling between stations.

A more complete description of the field sampling methods used during the HFBS can be found in Appendix A which is a copy of the paper titled "Avian Surveys of Large Geographical Areas: A Systematic Approach" by J.M. Scott, J.D. Jacobi, and F.L. Ramsey (1981).

Vegetation Mapping

A second major component of the HFBS was the preparation of vegetation map overlays at the scale of 1:24,000 for each study area. These maps describe the distribution and composition of the vegetation units, emphasizing four structural and floristic components: 1) tree canopy crown cover, 2) tree canopy height, 3) dominant tree species composition, and 4) understory species composition. A detailed discussion of the HFBS mapping program is provided in Appendix B (Jacobi 1983).

RESULTS

Description of Vegetation Units Found Within the Study Area

The vegetation types found in the Puna study area were mapped as overlays on the following five USGS quad maps at the scale of 1:24,000: Volcano, Kalalua, Pahoa South, Makaopuhi, and Kalapana. These individual map sheets were subsequently reduced to a smaller scale (1:48,000) and joined together to form a composite general vegetation map (Appendix C). On this latter map the major wet habitat vegetation types are displayed by eight colors. The composition and distribution of each wet habitat unit are discussed below.

1. Wet 'ohi'a forest with mixed subcanopy trees; treefern - native shrub understory. [Dark green].

The wet 'ohi'a forest with a treefern-native shrub understory is predominately found on the Campbell Estate lands north of the rift zone. This forest type grows on moderately old lava substrates which were erupted approximately 350 - 500 years ago (Holcomb 1980).

This unit is dominated by 'ohi'a (Metrosideros polymorpha), which forms either closed or open stands. Common subcanopy trees include olapa (Cheirodendron trigynum), kolea (Myrsine lessertiana), pilo (Coprosma sp), and kawa'u (Ilex anomala). The understory is chiefly comprised of hapu'u treeferns (Cibotium spp) or uluhe (Dicranopteris linearis) with a mixture of other native shrub and fern species. Below aproximately 750 m (2500 ft) elevation are found dense patches of 'ie'ie (Freycinetia arborea), a species believed to be an important food source for the endangered 'o'u (Berger 1972).

Although a few introduced plant species are found in this forest type, due to the relatively intact nature of the native tree canopy and understory, none of these introduced plants were found to be abundant enough to be included as a component on the mapping unit.

2. Closed-canopy, wet 'ohi'a forest with mixed native subcanopy trees; treefern - native shrub understory with some introduced shrubs and ferns. [Light brown].

This closed forest unit is found in the Puna study area only below the rift zone, generally confined to wet habitats below 750 m (2500 ft). It differs from the previous unit in both canopy cover and understory species composition. As mapped this unit consists of only closed canopy 'ohi'a forest (greater than 60% tree cover) which additionally includes a minor introduced shrub component (xs) in the detailed map unit symbol. Several important introduced plant species are found in this forest type including strawberry guava (Psidium cattleianum), melastome (Melastoma malabathricum), and sword fern (Nephrolepis exaltata). However, due to the fact that the 'ohi'a tree canopy is dense, the introduced plants are generally in low abundance, except in disturbed areas such as along roads or trails.

Floristically this mapped unit in the Puna study area lies within the lowland rainforest habitat, which contains a number of native plant species which have their distribution restricted to, or attain their greatest abundance, below approximately 750 m (2500 ft) elevation. Unique features of the lowland wet forest include dense patches of 'ie'ie, and the inclusion of subcanopy and shrub species such as 'ahakea (Bobea sp.), mehame (Antidesma platyphylla), olomea (Perrottetia sandwicensis), plus several species of haha (Cyanea spp), ha'i wale (Cyrtandra spp), ma'ohi'ohi (Stenogyne spp), and kapana (Phyllostegia spp). Similar differences in insect and other invertebrate populations can also be found between upland and lowland forests.

Lowland habitats in general have been particularly impacted by man's activities in Hawai'i. Today less than 10% of the original area of lowland 'ohi'a rainforest remains in the State and most of it contains at least a minor complement of introduced species. The largest expanse of relatively intact lowland rainforest is found in the Puna area, principally in lower portions of Hawai'i Volcanoes National Park and the James Campbell Estate lands. In the National Park this forest type extends down to approximately 600 m (2000 ft) elevation, below which the vegetation changes significantly due to reduced annual rainfall. To the east in the lower portions of the Puna Forest Reserve and the Campbell Estate lands, annual rainfall remains high at the lower elevations and relatively intact 'ohi'a rainforest can still be found down to below 300 m (1000 ft). This latter area represents one of the best and lowest examples of this forest type in the State.

3. Open canopy, wet 'ohi'a forest with mixed native subcanopy trees; treefern - native shrub understory with some introduced shrubs and ferns. [Light green].

This third unit is very similar to the previous lowland forest unit but with two closely related differences: 1) the tree canopy is relatively open with tree canopy cover ranging between 25 and 60%, and 2) due to the increased levels of light penetrating the forest, the populations of introduced plant species are either greater or have a high probability of rapidly increasing with any opening of the understory. As in the previous unit, two of the important introduced plant species are strawberry guava and melastome. Other plants of concern are several gingers (Hedychium spp) and, at higher elevations, faya tree (Myrica faya) and blackberry (Rubus penetrans).

The greatest extent of this open 'ohi'a forest type is in the Puna Forest Reserve and Natural Area Reserve, north of the rift zone. However, smaller patches are scattered throughout the study area at both higher and lower elevations.

4. Wet 'ohi'a forest units which have been damaged by recent eruptions (fire/fume damage). [Dark brown].

Adjacent to recent lava flows or eruptive vents are forest units which have been noticeably damaged by associated fire or fuming. In their current state these units have generally lost much of the original tree canopy and the understory vegetation was reduced following the eruptive activity. In many of these forest patches the opening of the vegetation has resulted in a subsequent change in species composition with a notable increase in the abundance of certain introduced plants. In our 1979 survey the understory in the large damaged forest patch south of Pu'u Kalalua was dominated by the introduced thimbleberry (Rubus rosaefolius). It would be useful to revisit some of these areas again to evaluate the revegetation process over a longer period of time.

Prior to the human introduction of numerous species of plants and animals, the recovery of forest units damaged indirectly by volcanic activity (such as by fire or fume), would have proceeded with the natural succession of a series of native plant associations which would eventually result in regaining the composition and structure of the surrounding wet forest. Today this natural successional process has been upset by the additional presence of highly invasive, non-native species which are well adapted to becoming established in disturbed habitats. The sequence of secondary succession in Hawaiian forest habitats on already developed soils is not well understood. This is partly because of the relatively short period of time they have been studied, but largely because new plants have been periodically introduced into Hawaii, some of which are even more aggressive than their predecessors. However, as long as a relatively intact native tree canopy and understory are maintained, it appears that introduced plants are not able to become well established or dominant in these habitats. On new lava flows, assuming a sufficient seed source in the surrounding forests, the vegetation which develops over time is still generally dominated by native species which are best adapted to the harsh environmental conditions associated with such young and poorly developed substrates.

5. 'Ohi'a - kukui forest with a mixed native shrub - introduced shrub understory. [Yellow].

The 'ohi'a - kukui unit occurs below 600 m (2000 ft) elevation on moderately-old ash soils. Kukui (Aleurites moluccana) is an indicator species of this unit but is not necessarily a co-dominant tree throughout. The 'ohi'a trees in this forest are generally larger in diameter than found in the rest of the Puna study area, and are chiefly the variety macrophylla.

The understory includes a great number of introduced plants and, in some areas, is dominated by strawberry guava, melastome, and/or swordfern. It is speculated that the abundance of introduced plants in this unit reflects past human disturbance, including some level of cultivation by the Hawaiians as evidenced by the presence of rock walls and mounds. Despite the disturbed nature of the understory, this community still does contain some rare plant species, and is utilized as habitat by several of the more connon native bird species.

6. Forest units dominated by introduced trees and shrubs. [Red].

Only two small patches of forest dominated by introduced trees and shrubs were mapped in the northeast corner of the Puna study area. These units have a tree canopy dominated by several introduced species including mango (Mangifera indica), guava (Psidium guajava), and possibly Eucalyptus. The understory vegetation is dominated by strawberry guava, but also includes aome native species such as hapu'u and uluhe.

7. Recent lava flows (1963-1985). [Gray].

Along the rift zone and extending to some degree makai of the rift are found young and generally sparsely-vegetated lava flows which were erupted between 1963 and 1985. Although these flows are not densely covered with vegetation, the plants which are beginning to colonize them indicate a normal succession of the vegetation to eventually become a wet 'ohi'a forest. The majority of plants found on these young lava flows are native species, including 'ohi'a, kupaoa (*Dubautia* spp), and 'amau fern (*Sadleria* spp). The most common introduced plants are babmoo orchid (*Arundina bambusaefolia*) and butterfly-bush (*Budleja asiatica*).

8. Wet pioneer 'ohi'a community (trees less than 10m tall). [Pink].

The wet pioneer 'ohi'a community is mapped both above and below the rift zone in the Puna area. It generally contains an open or nearly closed 'ohi'a tree canopy with an understory dominated by uluhe fern. This unit represents an early developmental stage in wet forest vegetation which will eventually become closed-canopy 'ohi'a-hapu'u forest. Although the rate of vegetation development in this area is chiefly a function of the age of the lava substrate and rainfall, it may also be significantly influenced by the type of lava flow the plants have to grow on. In this wet habitat the fastest rate of development can be found on broken lava substrates (either 'a'a or "shelly" pahoehoe). Preliminary carbon-14 dating of lava flows have indicated that a closed-canopy 'ohi'a forest could become naturally established on a thin, broken lava flow in the central, mid-elevation portion of the Puna study area in less than 250 years.

Most of the pioneer 'ohi'a vegetation below the rift zone appears to be developing relatively rapidly. The quickest rate of vegetation development here can be found on the 1840 'a'a lava flows in the southeastern section of the area. In this case the trees now form a nearly closed canopy after less than 150 years. The open scrub 'ohi'a forest in the somewhat drier habitat near and below Heiheiahulu is just over 200 years old.

The two main strips of pioneer 'ohi'a forest north of the rift zone are found on dense pahoehoe lavas over 300 years old. In these situations the poor drainage of the lava substrate has acted to retard the vegetation development, resulting in an open canopy of short, small-diameter 'ohi'a trees with an understory dominated by uluhe, grasses and sedges. It is very likely that these areas will never develop into tall forest units, but will always remain as short-statured, boggy communities.

Bird Populations

This section on bird populations was abstracted from a manuscript by Scott et al. (In Press) which discusses in detail the distribution, abundance, and status of all forest birds recorded during the HFBS for all of the major Hawaiian Islands except O'ahu.

1. Native Birds

During the HFBS we recorded 7 species of native birds and 7 species of introduced birds in the central portion of the Puna study area (Table 1). The most common native species was the 'apapane which was estimated at greater than 400 birds/km^2 over much of the study area. The highest density (>1600 birds/km^2) for this species in the area was near Thurston Lava Tube at approximately 900 m (3000 ft) elevation. However density values of 400 - 600 birds/km^2 were also found in forested units below 450 m (1500 ft) elevation.

The abundance of the 'oma'o and 'elepaio were also greatest in the upper elevation portions of the study area. However, both of these species were also regularly found in forest habitat below 600 m (2000 ft) elevation.

The 'amakihi populations were small (11-50 birds/km^2) in upper elevation areas, but an extremely high density of >1600 birds/Km^2 was .pa estimated for this species in the lower Campbell and Puna Forest Reserve lands south of the rift and below 600 m (2000 ft) elevation.

The endangered 'io (Hawaiian Hawk) was found throughout the study area. Although we did not calculate density values for the 'io during the HFBS, the Puna area, particularly below 600 m (2000 ft) elevation, is considered to include a significant portion of the island-wide 'io population, estimated to be between 1400 and 2500 birds (Griffin 1984).

The two rarest of the native species found in the Puna area were the 'i'iwi and the endangered 'o'u. Both of these species were found only in the closed 'ohi'a forest units in the central portion of the study area, between 900 and 450 m (3000 and 1500 ft) elevation. For both the 'i'iwi and the 'o'u, population densities in Puna were estimated to be less than 10 birds/Km^2. The locations of the 'o'u sightings recorded during the HFBS in the Puna area are presented in Fig. 3.

The distribution of "essential habitat" for endangered Hawaiian forest birds (specifically the 'o'u) in the Puna area is shown in Fig. 4 (Hawai'i Forest Bird Recovery Team 1982). Essential habitat is defined as "that area deemed essential to the long-term survival of the species in question". The evaluation of essential habitat is based on both the habitat and resources utilized by the endangered species. For the most part, the essential habitat of the 'o'u in Puna coincides with the distribution of closed canopy 'ohi'a rainforest on the north side of the rift zone. This area includes most of the upper part of the Kahauale'a parcel and a portion of the Wao Kele 'O Puna State Natural Area Reserve.

One other native bird which may use the Campbell Estate/Puna Forest Reserve lands is the endangered 'a'o (Newell's shearwater, Puffinus puffinus newelli). Although we did not record this species during the HFBS, a probable nesting colony has been reported in the Makaopuhi Crater area in the adjacent lands of Hawai'i Volcanoes National Park (Kepler et al. 1979). While the 'a'o is a seabird, it nests in wet forest habitats, particularly in dense mats of uluhe fern in the walls of pit craters or on pu'us (cinder cones). This type of habitat is found along the east rift zone in the Puna area.

2. Introduced Birds

Seven species of introduced birds were also found in the central portion of the Puna study area during the HFBS. By far, the most common of these species was the Japanese white-eye, which is ubiquitous throughout all forest habitats in Hawai'i. The other introduced species included the spotted dove, northern cardinal, nutmeg mannikin (ricebird), housefinch, melodious laughing thrush, and common mynah. These species were also generally found throughout the Puna forest areas, however, at much lower densities than the white-eye.

Rare Plants

During the HFBS we recorded information on nine species of rare plants in the central portion of the Puna study area (Table 2, Figure 3). Of this total, two species are Category 1 candidate endangered plants, one is a Category 2 candidate, and one is a Category 3C plant. The five additional plants included in Table 2 are considered to be relatively uncommon, but are not currently being considered for listing as endangered or threatened species.

Adenophorus periens is a small epiphytic fern which is found in the central portion of the Puna study area, concentrated in the closed 'ohi'a rainforest generally north of the rift zone (Figure 3). In his review of the Hawaiian species of *Adenophorus*, Bishop (1974) noted that *A. periens* "...has been collected on all of the islands on which rain forests occur.

Most of the collectors of the nineteenth century obtained it and Hillebrand...records it as 'not uncommon in forests above 2000 ft, hanging in graceful festoons from the trunks of trees.' Sheets from the earlier part of the present century bear the comment that the species was rare. Since 1935 it has been collected only near Glenwood on the island of Hawai'i."

Recent field work has indicated that Adenophorus periens's original wide distribution range has now been reduced to two areas: 1) the relatively large population in the Puna area (generally concentrated in the upper Kahauale'a forests, and 2) a samll population (less than 50 individuals) on the island of Moloka'i (C.H. Lamoureux, pers. communication). The reasons for the dramatic decrease in this species' range are unclear. Part of the explanation is certainly tied to the loss of forest areas which it was formerly found in. However, despite the presence of relatively intact habitats remaining in some of its early collection localities, Adenophorus periens is presently only relatively stable in the Puna area. Bishop (1974) commented that "...it therefore seems that the unexplained causes of the demise of A. periens have been as subtle as their effects have been decisive."

The two other high-priority candidate plant species, Bobea timonioides and Tetraplasandra hawaiensis, are typically elements of the lowland wet and mixed mesic forests (below 600 m (2000 ft) elevation), of which little presently remains. Several individuals of Tetraplasandra were recorded in the lower portion of the Kahauale'a lands. Although Bobea timonioides was found only in Hawai'i Volcanoes National Park during the HFBS, other populations are known from the Royal Gardens Subdivision and surrounding areas.

The remaining six species listed in Table 2 are considered to be fairly uncommon elements of the mid-to-low elevation 'ohi'a rainforest on the island of Hawai'i. Although these species are not currently recognized as candidates for listing as endangered or threatened, due to their relative rarity, some consideration should be given them in long-range planning for the area.

DISCUSSION

Today, less than 25% of Hawai'i's total area is still covered with naitve-dominated vegetation. The greatest changes have occured in lowland ecosystems where, starting with the Hawaiians, large portions of the landscape have been transformed into agricultural, residential, and urban use. The original plant and animal communities in many of the remaining areas not directly affected by human activities have become subject to new sets of competetive pressures from introduced species which have drastically, and in some cases permanently, altered the natural composition and strucutre of the native ecosystems.

One measure of the "uniqueness" of the Hawaiian biota can be found in the observation that nearly 95% of the native flowering plants and 99% of the native animals are endemic to Hawai'i (i.e. found no where else in the world) (Carlquist 1980). A similar measure of the degree of recent degradation of the native ecosystems over the last 200 years is seen in the current numbers of extinct and endangered or threatened species. Of 86 native terrestrial birds described in Hawaii since 1778, 28 are now extinct. Of the 58 remaining birds, 27 are listed by the U.S. Fish and Wildlife Service as "Endangered" or "Threatened" (U.S. Fish and Wildlife Service 1984). To put these figures into perspective, the Hawaiian birds on the Federal Endangered Species List represent nearly one-half of the total number of Endangered and Threatened birds from the entire United States. Two of the endangered species from the island of Hawai'i, the alala (Hawaiian crow) and the 'o'u, have precariously low populations, and may now, in fact, be on the verge of extinction.

The native plants have suffered similar losses. Approximately 270 of the estimated 3000 species, subspecies, and varieties of Hawaiian plants are believed to have become extinct since the late 1700's (Fosberg and Herbst 1975). Although the Fish and Wildlife Service has so far officially listed only 11 of the remaining plants as Endangered Species, nearly 800 additional Hawaiian taxa are currently being considered as high priority candidates for the listing process (U.S. Fish and Wildlife Service 1980, 1984).

While some level of rarity and extinction are expected in natural ecosystems, the enormous numbers of extinct and endangered species from Hawai'i reflect drastic alterations in the native communities, for the most part due either directly or indirectly to human activities. In addition, natural factors such as lava flows and fires also continue to affect the vegetation and species in certain areas like Puna.

The wet forest habitat in the Puna area does contain some rare and threatened native plant communities and species elements. The totally native-dominated 'ohi'a forest north of the rift zone [dark green unit on the map] serves as important habitat for the 'o'u and Adenophorus perians, as well as for several other rare native plants and birds. Also of great biological value is the closed lowland 'ohi'a rainforest [light brown unit] found primarily south of the rift. Although this unit does not contain as many rare elements as the first vegetation unit, it represents the most significant portion of remaining lowland 'ohi'a rainforest in Hawai'i.

From an ecological perspective one of the most notable features of the central and lower portions of the Puna study area is the diversity of different vegetation types, reflecting different stages of vegetation development on lava flows ranging in age from over 1000 years old to the present. Too often we tend to focus all of our attention on individualr species or forest types and fail to recognize the close relationships between these elements and the surrounding communities.

The challenge that we all face together in Hawai'i is to realistically evaluate our present and future development needs in the context of their long-term impacts on our remaining natural biological resources. One important step in this assessment process is to assemble the best set of information available on the current status and apparent vulnerability of native communities and species in areas where they overlap with planned development. This biological information can be used in much the same way that economic facts and models are used to provide necessary perspective in evaluating a proposed project. Hopefully through a broad-minded planning process we will be better able to both recognize and possibly minimize the trade-offs which may be required as we plan for our future.

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TABLE 1. Summary of bird species found in the wet forest habitats in the Puna Study Area during the Hawai'i Forest Bird Survey; data summarized from Scott et al. (In Press).

SPECIES	ORIGIN[1]	STATUS[2]	POPULATION[3]
'apapane *Himatione sanguinea*	N	NE	132,023
'amakihi *Hemignathus virens*	N	NE	32,465
'oma'o *Phaeornus obscurus*	N	NE	15,509
'elepaio *Chasiempis sandwicensis*	N	NE	8,576
'i'iwi *Vestiaria coccinea*	N	NE	191
'o'u *Psittirostra psittacea*	N	EN	9
'i'o *Buteo solitarius*	N	EN	1400-2500 birds on the island
Japanese white-eye *Zosterops japonica*	X		158,182
House finch *Carpodacus mexicanus*	X		7,301
Cardinal *Cardinalis cardinalis*	X		6,044
Melodious laughing-thrush *Garrulax canorus*	X		3,146
Nutmeg mannikin (Ricebird) *Lonchura punctulata*	X		2,449
Common mynah *Acridotheres tristis*	X		337
Spotted dove *Streptopelia chinensis*	X		258
Red-billed leiothrix *Leiothrix lutea*	X		30

[1]ORIGIN: N = Native to Hawai'i; X = Introduced to Hawai'i
[2]STATUS: NE = Not Endangered; EN = Endangered
[3]POPULATION: Population estimate for the entire Puna study area.

TABLE 2. Rare native plants recorded during the Hawai'i Forest Bird Survey in the central portion of the Puna study area.

SPECIES	STATUS[1]	ON CAMPBELL ESTATE LAND	IN PUNA FOREST RES
Adenophorus periens	1	YES	YES
Bobea timonioides	1	?	
Tetraplasandra hawaiensis	2	YES	YES
Clermontia hawaiiensis	3C	YES	
Bobea Hookeri	–	YES	YES
Clermontia sp.	–	YES	YES
Phyllostegia vestita	–	YES	YES
Phyllostegia villosa	–	YES	YES
Xylosma hawaiiense	–		

[1] STATUS: 1 = Category 1 candidate for listing as endangered or threatened.
2 = Category 2 candidate for listing as endangered or threatened.
3C = No longer a candidate for listing.
– = Not currently a candidate for listing.

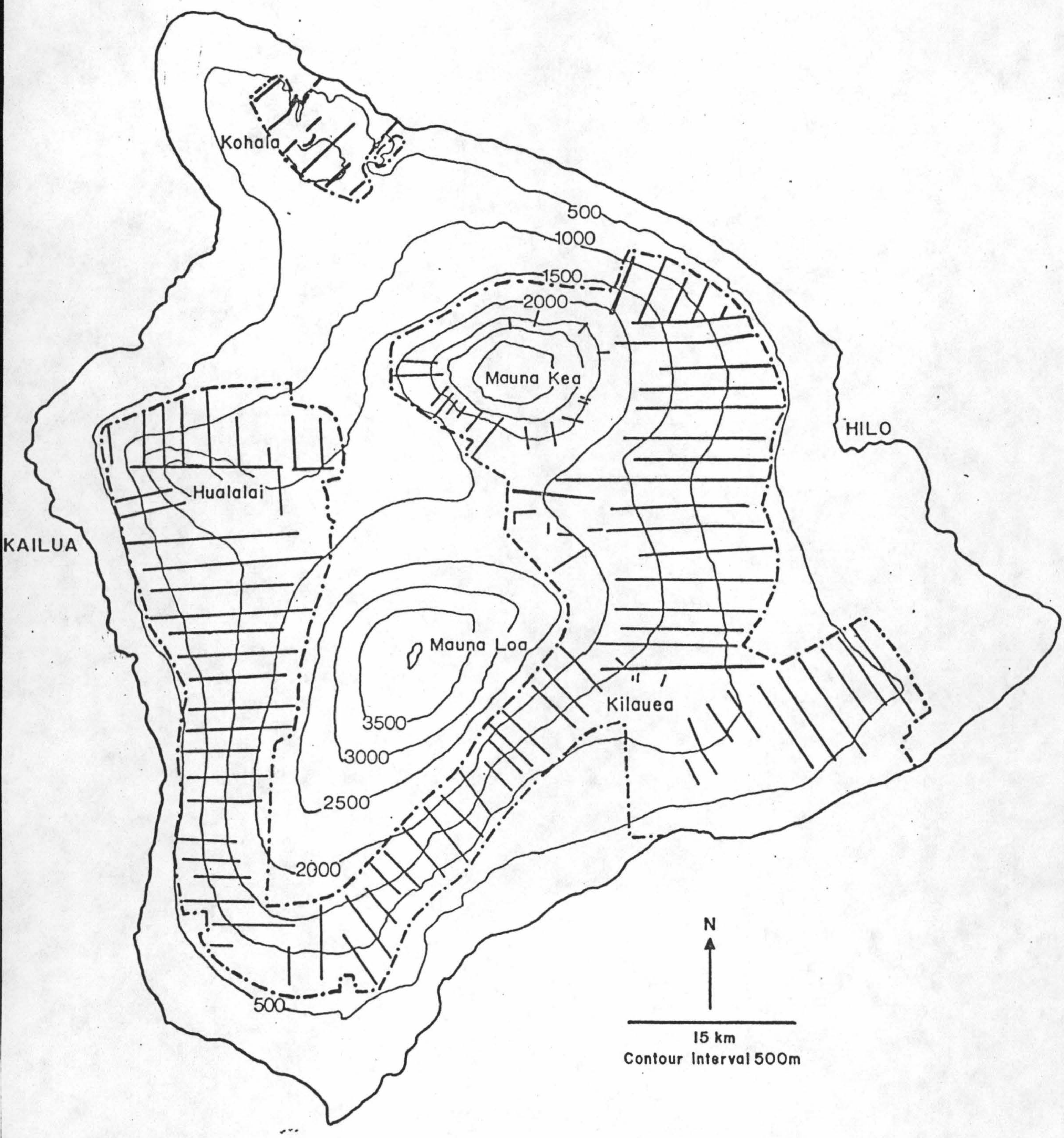

Fig. 1. Location of the study areas and transects sampled on the island of Hawaii during the Hawaii Forest Bird Survey.

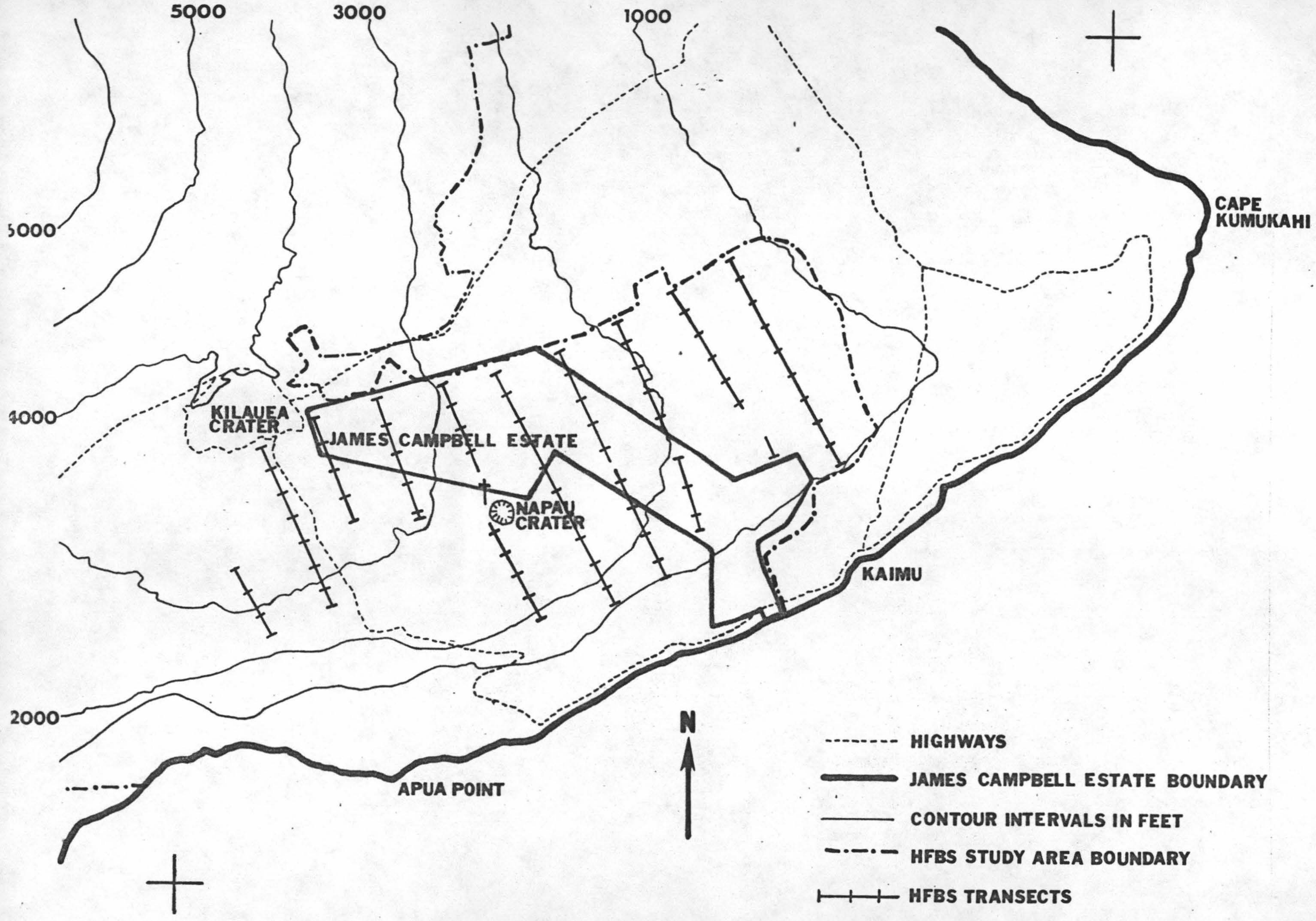

Fig. 2. Location of the Hawai'i Forest Bird Survey transects established in the Puna study area.

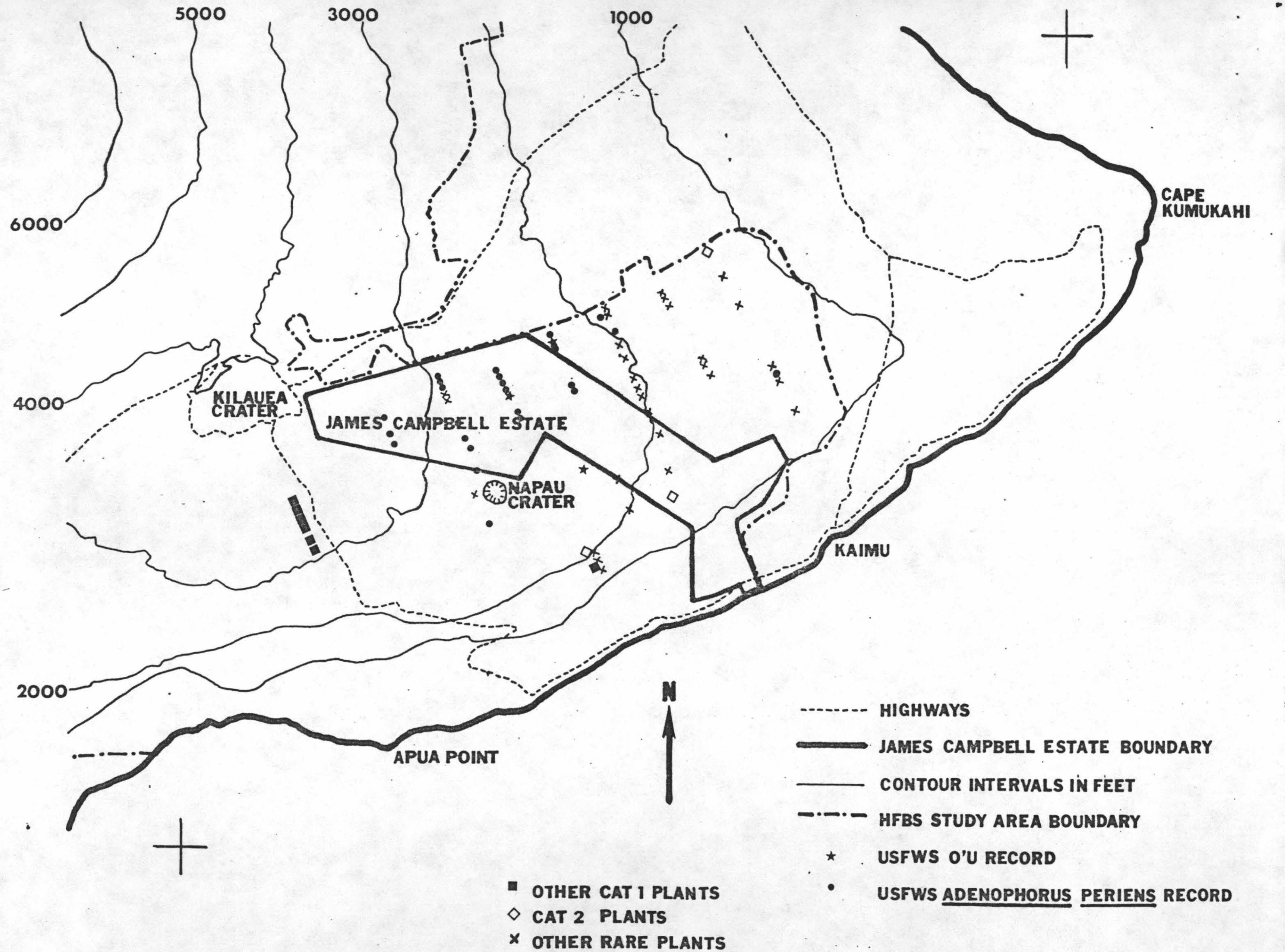

Fig. 3. Locations of rare native bird and plant sightings made during the Hawai'i Forest Bird Survey.

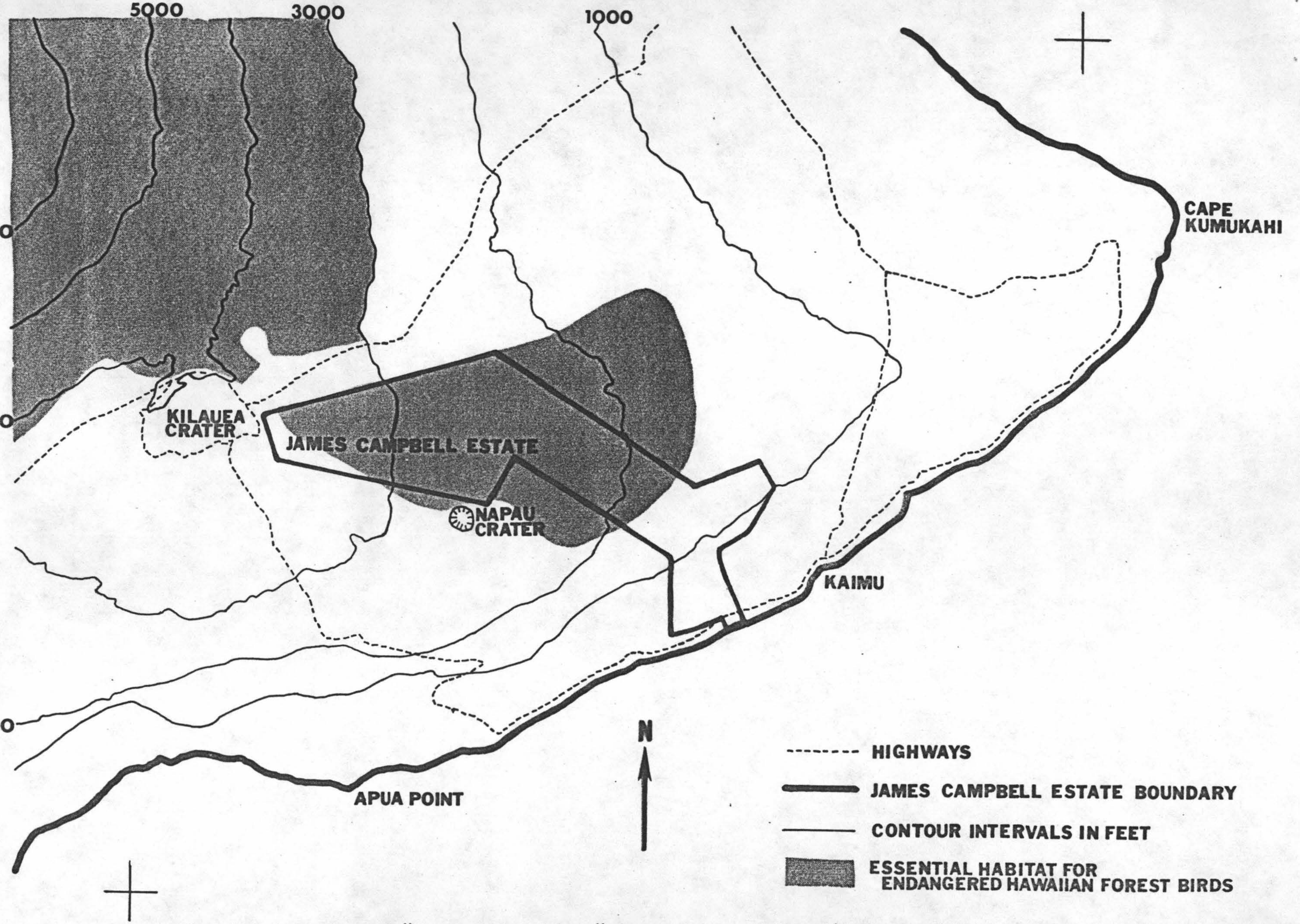

Fig. 4. Location of "Essential Habitat" for endangered Hawai'i forest bird species on the eastern portion of the island of Hawai'i. (from: Hawai'i Forest Bird Recovery Team 1982).

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AVIAN SURVEYS OF LARGE GEOGRAPHICAL AREAS: A SYSTEMATIC APPROACH

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Abstract: A multidisciplinary team approach was used to simultaneously map the distribution of birds, selected food items, and major vegetation types in 34,000- to 140,000-ha tracts in native Hawaiian forests. By using a team approach, large savings in time can be realized over attempts to conduct similar surveys of smaller scope, and a systems approach to management problems is made easier. The methods used in survey design, training observers, and documenting bird numbers and habitat descriptions are discussed in detail.

Large areas of the world are poorly known biologically because they are thought to be too large, rugged, or remote to study. Many of these areas may have a large number of rare, poorly known, or possibly undescribed species that are threatened by the increasing pressure of human populations. Basic information on distribution, density, population size, and habitat correlates of these species is often lacking, but it is badly needed to make rational management decisions in their behalf. In many instances we simply need to know where a species can be found consistently so that detailed ecological studies can be started or refuges established.

In only a few cases, the distributional patterns and abundance of single species over its entire range have been determined (Kepler and Kepler 1973, Kepler and Parkes 1972, Mayfield 1972, van Riper et al. 1978). Simultaneous determination of the occurrence of selected habitat variables relative to a species is undertaken even less frequently.

As increasing demands are placed on limited land areas, it is important that we have statistically reliable information to help us identify rare or threatened species before they become endangered in addition to determining the impact of habitat alterations on their populations. Equally important is having this information easily accessible through a computer-based geographical information system that could provide resource managers with immediate answers to a wide range of basic questions (e.g., How many individuals of species A are present? Where are the best areas for detailed studies of species A? What percentage of the range of population or species A or vegetation type A will be affected by proposed land uses?). If the true status of a species can be determined, it may result in the listing of a new endangered or threatened species or possible deletion of one. But, perhaps more importantly, such information helps produce a second generation of questions on species distribution and status, and it promotes thinking about systems and entire populations or communities rather than about individual species or isolated areas within a species' range.

Hawaii, perhaps more than anywhere else on earth, needs such information.

More taxa of birds (21) have become extinct there than in any other comparable area; 52.6% of the 57 U.S. taxa listed by the U.S. Fish and Wildlife Service (1980) as being endangered or threatened are endemic to Hawaii.

A statewide survey of the birds in areas of native vegetation on all of the major Hawaiian Islands was begun by the U.S. Fish and Wildlife Service in 1976. Through 1980, >3,000 km² of bird habitat has been surveyed on the islands of Hawaii, Lanai, Molokai, and Maui.

The objectives of the Hawaii Forest Bird Survey (HFBS) were to determine: (1) the distribution of all forest birds, with emphasis on the native species; (2) bird density (birds/km²) by vegetation type and elevational stratum; (3) the population size for all forest birds in each study area; (4) bird/habitat correlations; (5) the distribution of native vegetation types on all of the islands; (6) land-use patterns and stability of habitats within each species' range; (7) geographical areas in which more detailed studies can be undertaken to clarify distributional anomalies and to identify limiting factors of various species; and (8) determine distribution of rarer plants. A secondary objective of the HFBS was to develop, improve, and continually evaluate forest bird survey techniques and their methods of statistical analysis. The primary objectives of the survey are met by simultaneously surveying the forest regions, and describing and mapping vegetation types and selected habitat features throughout the different study areas.

Since the Hawaiian Islands present extremes of terrain and weather, the methods being used there may well prove adaptable to similar studies in other parts of the world. This paper focuses on the practical problems of conducting a detailed avian survey of a large area where access is limited and detailed information on habitat features and animal occurrence is desired. Many of the theoretical questions of sampling birds and plants have been addressed elsewhere (Anderson et al. 1976, Burnham et al. 1980, Cochran 1963, Eberhardt 1978, Mueller-Dumbois and Ellenberg 1974, Seber 1973).

Many people have contributed to the development of the sampling regime given in this paper. We particularly wish to thank E. F. Kridler, J. L. Sincock, T. L. C. Casey, C. van Riper III, C. B. Kepler, and F. R. Warshauer for their contributions. J. L. Sincock, C. B. Kepler, C. J. Ralph, and C. van Riper III made many helpful suggestions on early drafts of the manuscript.

STUDY DESIGN

Selection of Study Areas

The 1st step in surveying an area is to identify discrete vegetational or topographic units that can be surveyed within your time, budget, and man-power limits. If at all possible, these areas should contain discrete populations of the species of interest that will make estimates of population size and density more meaningful. Sampling of these units is then conducted at stations established at regular intervals along transects running through each area. In Hawaii, where each island is basically a mountain or group of mountains, a series of parallel transects are laid out running perpendicular to elevational contours. In flatter areas, transects should run at right angles to major vegetational features to minimize sampling biases. Ramsey (1979) has argued that running transects perpendicular to contours of any variable that is known to be correlated with density will also make the actual survey situation more closely fit the mathematical model that is assumed for statistical analysis.

Logistical Support

The number of people and vehicles necessary to keep a team of 8 ornithologists, 4 botanists, and 6 trail crew members in the field depends on the size of the units sampled, access, and type of terrain. After much trial and error we feel that 1 field supervisor and 3 assistants are adequate to ensure smooth running field operations. Additionally, 1 vehicle for every 4 field people is necessary for tactical support. The number of support people could be reduced if the trail laying and sampling efforts did not overlap.

Determining Transect Spacing and Station Intervals

We identify the location of the initial transect by random draw; all subsequent transects are laid at regular intervals from this starting point (Anderson et al. 1976). The spacing of transects should be systematic rather than random when distribution is an important question (Eberhardt 1978). The distance between transects should be based on the distributional patterns of the species of interest and should be small enough to ensure that at least 3 transects pass through any species' range. In Hawaii, where bird species are frequently restricted to very small areas, 3.2-km (2 mi) and 1.6-km (1 mi) intervals were used between transects. The distribution of Akiapolaau (*Hemignathus wilsoni*) was used to determine transect spacing. This bird is one of the rarer and more patchily distributed species on the island of Hawaii. The species' distribution is shown in Fig. 1.

Marking Field Sites

The top and bottom of each transect are determined by presence of suitable habitat. After the transects are drawn on 1:24,000 scale topographic maps, trail crews mark them in the field.

Our trail crews usually consist of 3 individuals, however, 2 person teams can be used when the terrain is very open. Effort is minimized if trails are laid from the highest to the lowest elevation. The lead person determines the correct compass heading. Moving ahead as rapidly as common sense, accuracy, and terrain permit, he moves through the undergrowth and flags with just enough plastic surveyor's tape to allow the 2 trailing people to follow him. These 2 people use a premeasured polypropylene rope to determine distances between stations. The leading end of the rope is weighted so it can be easily tossed over obstacles. The trailing pair flags the trail more completely and identifies sampling stations at predetermined intervals by marking each with numbered aluminum tags.

The distance between stations should be based on the distance at which the most conspicuous target species can be consistently detected. But one should be careful in selecting these distances. If the most conspicuous species is highly conspicuous, you may lack sufficient sampling intensity to learn much about a very rare inconspicuous species limited to a narrow elevational band. In that case, one should use a smaller distance between stations. To obtain independence one can always use data from every 2nd or 3rd station to study conspicuous species. For instance, observers had effective detection distances (Ramsey and Scott 1981) of 31–76 m for the Hawaiian thrush (*Phaeornis obscurus obscurus*),

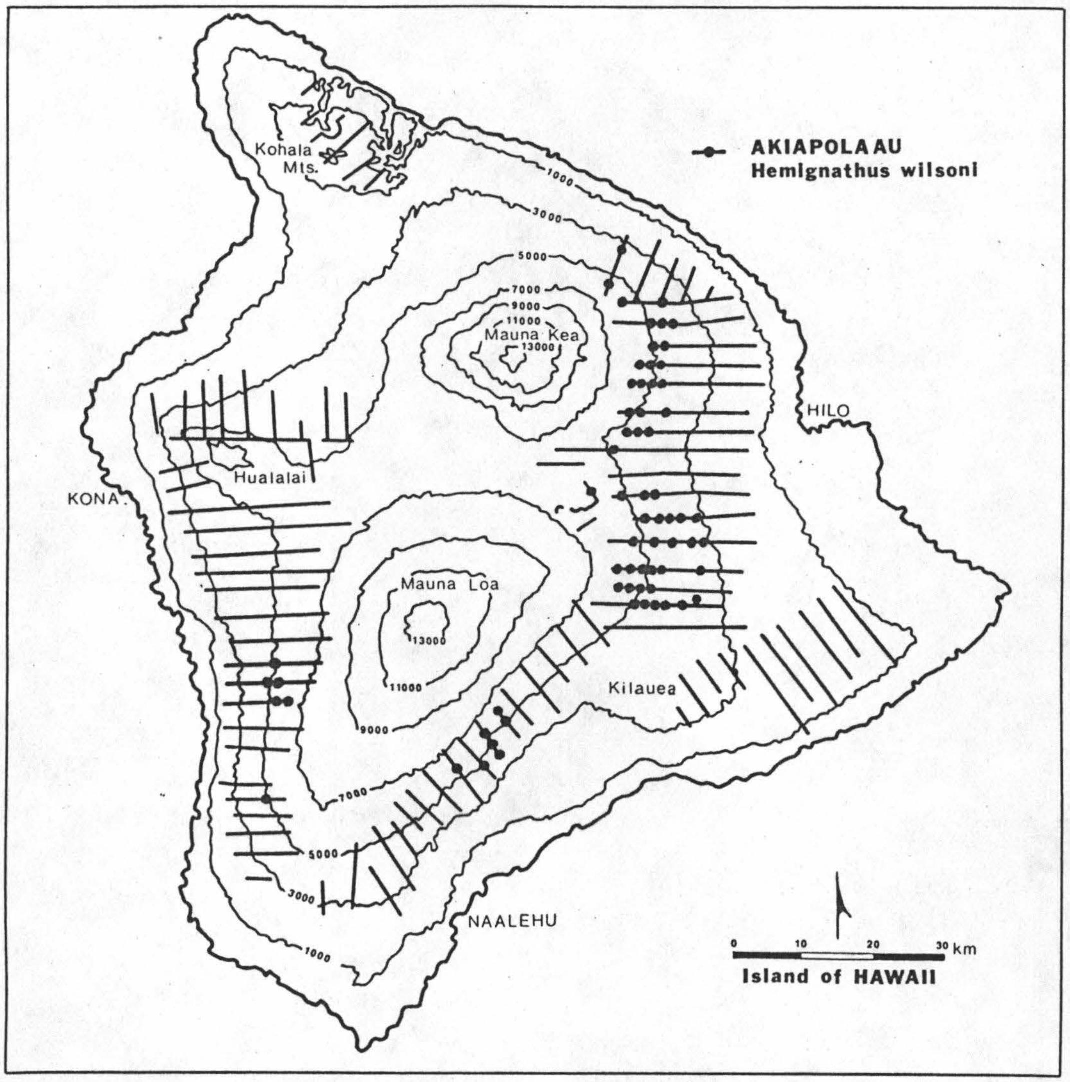

Fig. 1. Distribution of one of the rare Hawaiian birds, Akiapolaau (*Hemignathus wilsoni*) is shown relative to the placement of transects on the island of Hawaii. The transects are at 3.2-km intervals, and the area surveyed during the 4-year survey exceeded 300,000 ha. Each circle represents 1 or more Akiapolaau observed during an 8-min count period.

the most conspicuous forest bird on the island of Hawaii. We used this information to establish stations at 134-m intervals along each transect, more than twice the average effective detection distance for this species (Ramsey and Scott 1979). Such placement gives a degree of statistical independence to samples from adjacent stations.

Additional different colored flagging is hung 10 and 20 m before and after each station to help bird observers determine distances, to anticipate the stations when moving along a transect, and to act as points of reference for distance estimation by biologists. The trail crew also takes detailed notes on access, travel time to transect, location of camp sites, water, safety hazards, and other items that may be useful to those following behind it.

The trail crew's rate of travel varies with the ruggedness of the terrain and density of the vegetation; a travel rate of ½–6 km/day was accomplished in Hawaii. In establishing >1,100 km of transect, we found that for a 15 km transect we can consistently come within 0.25 km of the predicted bottom point.

Finally, actual positions of the transects and stations are plotted in the field on aerial photographs. This information is later transferred to 1:24,000 topographic maps to be used in mapping vegetation type and bird distribution.

Team Safety

In rugged and isolated areas, field crew safety is a primary concern. Each team should carry a good, lightweight, waterproof 2-way radio and make radio contact twice each day with the field supervisor. Ideally they should be able to contact the supervisor at anytime. Before beginning field work the appropriate emergency agencies should be contacted and provided with detailed maps indicating the position of each transect and station as well as the radio frequency being used. In case of an emergency this information will enable them to respond more rapidly to the situation. Basic first aid training and equipment should be provided for each team member. Rescue equipment (e.g., climbing ropes, lights, food, etc.), for use by support teams, should be packed and ready for use. Additionally, all team members should be thoroughly briefed and provided with written instructions concerning procedures to follow in an emergency situation.

Relationships with Landowners

The importance of maintaining good relationships with landowners cannot be overemphasized. Survey team members should be advised that they are guests of the landowners and should conduct themselves accordingly. If while conducting the survey any problems are found, e.g. downed fences, broken gates, wandering livestock, etc., the landowner should be notified immediately. Also, team members should be told that if they accidently damage property in any way that they not try to cover it up but immediately notify the field supervisor, who will then contact the landowner. This will ensure good working relationships over the long-term. Follow-ups with landowners will also help in this regard.

AVIAN SURVEY

Sampling Methods

A variety of methods are available to estimate bird numbers (see Berthold 1976 and Emlen 1971), and the particular method chosen will depend on the objectives of the researcher, behavior of the birds, and the terrain and vegetation of the area surveyed. In many areas >1 technique will have to be used to adequately inventory such diverse groups as perching birds, diurnal and nocturnal raptors, and waterfowl. We have found the variable circle count method (Reynolds et al. 1980), with modifications

(Ramsey and Scott 1979, 1981), to be the best method for estimating bird numbers in the Hawaiian rain forests where rugged terrain and dense vegetation make it extremely difficult to move about. A line transect does not provide bird numbers that can be associated with a fixed geographical location. It cannot be used in the same way that our "transects" are. A line transect is useful in *uniform* open habitat where density is constant. It may also be preferable for certain species (e.g. gallinaceous birds) that may move away from observers as they approach a station. In open terrain, line transect counts may be preferred (Burnham et al. 1980, Emlen 1971) because of the larger area surveyed/unit of effort.

For safety reasons 2 biologists are assigned to each transect in the Hawaiian rain forests. The stations are sampled independently but simultaneously by the 2 observers who are 18.2 m apart (Scott and Ramsey, in press). To minimize variables affecting detectability we use the following restrictions: (1) observations are recorded only during the 1st 4 h after dawn; (2) counts are conducted only during periods with winds <4 on the Beaufort Scale (21–29 kph); and (3) counts are conducted only when noise from rain or water dripping from vegetation does not interfere with listening.

At each station the observers count birds in an 8-min count period, during which they record all birds heard or seen and the initial detection distance for each observation. The portion of the 8-min period that is devoted to surveying a particular species is variable, depending upon the calling and movement rates of the species (Scott and Ramsey 1981), and upon the richness and expected numbers of individuals in the area being surveyed (Scott and Ramsey, in press).

Training Bird Observers

Even experienced bird observers should be trained in survey techniques and in field identification of the species of interest before a survey begins. This training period will help to standardize observations and eliminate bias due to observer differences that can be severe (Berthold 1976, Enemar 1962). In Hawaii, where we deal with only 20–30 species/year, it is possible to train avid bird watchers who have had no prior experience with Hawaiian forest birds and habitats in 2–3 weeks of intensive work. At the end of this training period they perform as well as the most experienced observer.

To maximize the observer's familiarity with the birds, the training period is best held in the area where the actual survey will be conducted. Training sessions should be structured so that techniques and species are added gradually. Field guides, tape recordings of calls and songs, study skins, simultaneous counts with experienced observers, lists of expected species, and repeated exposure to the birds should be used. Frequent simultaneous counts by 2 or more observers should be conducted daily after the 1st or 2nd day of training. Immediately following a simultaneous count period each observer should be asked which species he recorded. This procedure makes it easier to identify species that are being overlooked ("window species") or misidentified. More details of training techniques are given in Kepler and Scott (1981).

Distance Estimation

Estimating distances to birds heard but not seen is potentially a large source of error in survey efforts requiring these values (Emlen 1971). A great deal of training time should be devoted to this problem. We have found that it is best to have a small group of observers independently estimate the distance to a bird that is heard but not seen, then locate the bird and measure the distance to it. If this is done repeatedly for a variety of calls and songs, observers can become very consistent and accurate (average ±10%) in their distance estimates (Scott et al. 1981).

Small optical range finders (effective to 200–300 m) are very useful for accuracy in determining distances while actually conducting counts on station. However, in practice the distance to 2 or 3 landmarks is measured before a count period begins, and other distances are interpolated or extrapolated from these. We recommend flagging known distances as a further aid in estimating distances. Experienced observers rely less and less on range finders as they gain confidence in their ability to accurately estimate distances.

Field Forms

Field forms should be printed on waterproof paper to reduce the possibility of damage in the field. The forms are designed so that the information can be transferred directly to magnetic tape or cards without an additional transcription step. Consulting with keypunch operators and programmers before finalizing field forms can save time and money.

Immediately after finishing a count, each day's forms are reviewed to ensure that all required information was recorded. Immediately after leaving the field, forms are duplicated, and the originals are sent for keypunching. If possible, data should be entered into the computer or onto final work sheets immediately so that the observer can verify printouts before he returns to the field.

BOTANICAL SURVEY

An integral part of the HFBS has been the simultaneous sampling of the vegetation in the different study areas. This information provides an ecological basis for determination of habitat requirements for different bird species and allows for a clearer insight into identifying the factors that contribute to the distribution and stability of their habitats.

For the HFBS, the vegetation is described in 2 ways: (1) detailed descriptions of the vegetation and selected habitat features are made at the stations along each transect, and (2) detailed vegetation maps are prepared for each study area. Additionally, as much information as possible is collected on rare or endangered plant species that are encountered in the field.

Field vegetational sampling is done by 2-person botanical teams. The botanical teams can cover about twice as much transect distance daily as the bird survey teams since the botany teams are not limited to a 4-h sampling window. Therefore, 1 botany team : 2 bird teams was found adequate for this survey.

Detailed Habitat Descriptions

For the present survey, a habitat description format has been developed that allows for a rapid, yet fairly detailed and consistent assessment of the major habitat features in the field.

Eight types of habitat information are recorded along the transects: (1) general description of the vegetation type; (2) phenological data for selected plant species; (3) a sample of the vegetation structure and floristic composition at selected stations; (4) estimates of tree diameter (maximum, minimum, and mode) at selected stations; (5) notes on tree stand vigor; (6) notes on the distribution of aggressive weedy plant species encountered; (7) assessment of feral animal presence and damage to the vegetation; and (8) lava flow or soil type along the transects.

The vegetation type description includes categories for tree crown cover, tree height, tree species composition, and ground cover or understory type. Crown cover is estimated in the following classes: *closed canopy* (>60% cover), *open canopy* (25–60% cover), *scattered trees* (5–25% cover), and *very scattered trees* (<5% cover, with trees widely spaced). Tree canopy height is also estimated and recorded in 3 classes: *tall stature* (>10 m), *medium stature* (5–10 m), and *low stature* (2–5 m).

Phenology of selected tree species is recorded for 10 individuals at each station. Intensity of the phenophase (either flowering or fruiting) is rated on a scale of 0–4 (0 = no flowers or fruits, 1 = <1% of the crown covered with flowers or fruits, 2 = 1–5% cover, 3 = 5–25% cover, and 4 = >25% cover of flowers or fruits).

Vegetation structure and floristic composition are sampled at irregular intervals along the transects using the relevé method (Mueller-Dombois and Ellenberg 1974). Sampling points in this case are taken at the start of each transect and whenever there is a major change in the vegetation. For each station sampled in this manner, total plant cover is estimated to the nearest 10% for all recognizable vegetation layers: ground cover (0–0.5 m), small shrubs (0.5–2 m), tall shrubs (2–5 m), small or sub-canopy trees (5–10 m), and tall trees (>10 m). Additionally, all species within a vegetation layer are listed and their cover rated using a modified version of the Braun-Blanquet cover-abundance scale. Although this method is considered to be semi-quantitative (i.e. based on estimations rather than on actual measurements), it is sufficient to allow us to prepare a generalized vegetation profile for each of the different vegetation types encountered on transect.

Vegetation Mapping

Preparation of vegetation maps allows the bird survey information to be related to the distribution of the plant communities across an entire study area. For this survey, the vegetation type overlays are prepared at the scale of 1:24,000, and the map units describe the vegetation in a similar but less detailed manner than field descriptions along transects. Again, tree canopy cover, tree height, tree species composition, and ground cover type are distinguished. But the species associations are more generalized, and for the most part, only units >2 ha are displayed.

The distributions of the different vegetation types recognized are initially interpreted on aerial photographs at the approximate scale of 1:45,000 using a mirror stereoscope with 3× and 6× magnification. These preliminary map units are then verified on the ground during the field session by the botanical teams making the detailed descriptions of the vegetation along the transects. Additionally, time is spent getting an overview of the area from a small airplane or helicopter, to help resolve interpretation problems in areas not covered on the ground. Finally, the corrected map unit boundaries from the aerial photographs are compiled onto a USGS 7.5 min quad map base using a Kern PG-2 plotter.

The 1st vegetation map to be produced by the Hawaii Forest Bird Survey

Table 1. The Hawaii Forest Bird Survey team is composed of 26 individuals. Their primary responsibilities are given below.

Position	No.	% of year employed	Primary responsibilities
Senior scientist	1	100	Experimental design, data analysis, write-ups, daily schedule, training, overall responsibility for program.
Statistician	1	30	Experimental design, data analysis.
Administrative officer	1	30	Handles hiring, payroll, etc.
Field supervisor	1	100	Ensuring that equipment is ready for use, vehicles running properly, teams in woods, 1st response in in case of accident.
Field assistants	2 1	50 100	Radio checks, pickups and dropoffs, equipment repair.
Ornithologists	8	30	Documentation of bird distribution and abundance.
Botanists	2 3	50 30	Documentation of rare plant distribution, characterization of vegetation structure, species composition and phenology of selected species of plants: 4 in field, 1 in office working with vegetation mapping.
Trail crew	6	50	Responsible for flagging trails, taking detailed notes on safety hazards, presence of water, and camp sites.

was published at the scale of 1:48,000 without a topographic base (Jacobi 1978). However, all future maps will include elevational contours for better field reference.

Training Botanists

During the training session preceding each field season, all members of the botanical teams work together in the field for several days. Emphasis at this time is placed on calibrating plant cover and height estimates, and agreeing on field nomenclature for taxonomically confusing plant groups. Additionally, as the botanists record a great deal of information on different habitat components, field note formats are standardized to facilitate later data transcription.

TIME REQUIRED TO ACCOMPLISH SURVEYS

The time required to survey an area will vary with the weather conditions, sampling period allowed for birds (time on station), length of period during the day that counts can be made, sampling intensity, and access time. Assuming the sampling framework shown in Fig. 1 and a field team composed of 8 ornithologists and 4 botanists (Table 1), 48 stations, equivalent to coverage of 2,000 ha, can be surveyed for each day in the field.

DATA ANALYSIS

The initial detection distances determined for all birds recorded on station are used to calculate an effective area surveyed for each observer, species, and different general vegetation type (Ramsey and Scott 1979). This area surveyed is then used to determine density of each species at each particular station. Density and population estimates are then made for the different habitat types and elevational strata within the study area (Ramsey and Scott 1979, Reynolds et al. 1980). The rules we use for determining the distributional area of a species are: (1) If a species occurs in a given vegetation type, its range is considered to be the limits of this vegetation type within a 200-m elevational stratum and half the distance to the adjacent transects. (2) If a vegetation type is sampled within an elevational stratum and a species does not occur in it then that vegetation type is omitted as part of range for that elevational stratum unless this vegetation inclusion is surrounded on 3 or more sides and is less than 20 ha in area. (3) If a vegetation type is not sampled and species occurs within elevational strata then include vegetation type in range *unless* species is known *not* to occur in that vegetation type. (4) If a vegetation type is sampled and a species is not found during survey, but it is found in the same vegetation type at lower elevation or the same elevation on an adjacent transect or as result of incidental observations, then include that vegetation type as part of range. (5) Not all situations are covered by the above guidelines. In anomalous situations, judgment to include or not include an area in the range of a species is based on more general usage of similar habitat at similar elevations.

Multivariate statistics can be used to relate the distribution and abundance of birds and other organisms to both the structural and floristic features of the vegetation and phenological phase of selected species of plants.

DISCUSSION

The type of approach detailed here for sampling birds and their habitats could be used in many areas on the islands of the Pacific (e.g., Palau, Samoa, Marianas, etc.); national parks, forests, and wildlife refuges; the vast tracts of unexplored rain forest in the tropics; or single vegetation types extending over large areas (e.g., riparian habitat, ponderosa pine forests). In those areas of the tropics where there are large numbers of species (>150) it might be most practical to train observers to be specialists for specific groups (see Scott and Ramsey, in press). The methods we used in Hawaii are especially useful where long stays in the woods (10–11 days) are required and where rugged terrain and concern for safety of observers are complicating factors.

The team approach allows large geographical areas to be surveyed in a single season, thus permitting population estimates to be made for the individual species encountered. The simultaneous mapping of vegetation permits a critical evaluation of habitat stability, habitat correlates, and identification of gross distribution anomalies that, if studied in detail, might result in determination of limiting factors for the birds.

Surveys of the type outlined in this paper are expensive. However, they offer many advantages over studies of smaller areas or by fewer people: (1) sampling over large portions of the entire range of a species or ecosystem within a short time frame; (2) early determination of true problem species; (3) assessment of the status of species and major vegetation types; (4) ability to approach management questions on a community rather than single-species basis; (5) early prioritization of additional research or management needs; (6) assessment of best possible areas to set aside as natural area reserves based on detailed information for species range or ecosystem; and (7) establishment of baseline ecosystem conditions, changes that can be monitored through time by well-designed, low-intensity, random sampling procedures.

Despite the expense of the type of survey we described in this paper, we feel that this initial expense is well justified by the fact that it allows research team members to focus quickly on more specific research questions or management activities once the initial survey has been completed. In the long run this approach should in fact be far less costly than having to wait several years for the results of a smaller scope survey while the resource problems and their solutions intensify and costs of solving them increase.

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MAPPING THE NATURAL VEGETATION OF THE HAWAIIAN ISLANDS[1]

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INTRODUCTION

Since 1976 I have conducted a vegetation mapping program that, when completed, will encompass most of the areas of native vegetation above 500m elevation on all of the major Hawaiian Islands (Figs. 1,2). The primary purpose of this project was to provide a set of updated vegetation maps as a base for detailed ecological studies by two research programs.

One of these projects, the Hawai'i Forest Bird Survey conducted by the U.S. Fish and Wildlife Service, seeks to determine the present distribution, abundance, and stability of native forest bird populations and their habitats, with emphasis on endangered species (Scott, Jacobi, and Ramsey 1981). Nearly one-half of the officially listed or candidate endangered species of plants and animals in the United States are from Hawai'i, despite its very small land area (U.S. Fish and Wildlife Service 1980).

The second research project I am working with is the 'Ohi'a Rain Forest Study, working out of the Department of Botany at the University of Hawai'i in Honolulu. This project concerns the dynamics of the native wet forests on the windward side of the island of Hawai'i, focusing on determining the causes and results of a recent, large-scale dieback of the dominant tree species Metrosideros polymorpha (Mueller-Dombois 1980, Mueller-Dombois et al. 1980).

This new series of vegetation maps will provide the regional framework necessary to integrate the more detailed plant community and bird population sampling conducted throughout our study areas.

Previous Vegetation Maps for Hawai'i

Several vegetation maps have been produced previously for the Hawaiian Islands. In 1942, Ripperton and Hosaka published a map depicting the vegetation zones of Hawai'i. The map was at the scale of 1:500,000 for all of the Islands except Hawai'i, which was mapped at 1:1.5 million. This map set provides a good, but very generalized, overview of potential vegetation zones, based on a combination of existing vegetation, climatic patterns, and topography. However, we felt that this map's scale, plus the lack of differention between actual vegetation boundaries, would not allow this map to serve as anything more than a general basis for our purposes.

In 1963 the U.S. Forest Service and the Hawai'i State Division of Forestry completed the Hawai'i Forest Type Map Series at the scale of 1:62,000 (Honda and Klingensmith 1963). Despite the greater level of detail possible at this map scale, the Forest Type Maps had two major drawbacks: 1) the map units were designed to describe the vegetation from the timber-potential point of view and did not include much information on other non-timber species; and 2) these maps were prepared at the reconnaissance level with a limited amount of verification in the field.

More recently, Mueller-Dombois and Fosberg (1974) produced a vegetation map of Hawai'i Volcanoes National Park, located on the island of Hawai'i. This map, at the scale of 1:52,000, was detailed and accurate enough to meet our needs; however, it covered less than 5% of our study area.

Because of the lack of a recent, detailed vegetation map covering the areas of native vegetation in Hawai'i, the U.S. Fish and Wildlife Service initiated a new mapping program. For these maps, we generally adopted Mueller-Dombois and Fosberg's vegetation classification system, but since we dealt with a larger and more variable area, we expanded the system to allow more flexibility and consistency in defining map units.

The first product of this new mapping program was a vegetation map of the Ka'u Forest Reserve and adjacent lands, located on the southeastern portion of the island of Hawai'i (Jacobi 1974). The same mapping strategy has been used for subsequent areas, however, the map symbol format has been slightly modified to allow for more flexible description of the mapped units.

METHODS

This new vegetation map series is compiled at the scale of 1:24,000. The basic patterns of the vegetation were mapped at the scale of 1:40,000 on black and white aerial photographs taken by the U.S. Geological Survey in 1976 - 1978. This initial mapping step was accomplished by using a mirror stereo-scope with 3X and 6X magnification. The boundaries delineated on the aerial photographs were compiled into a preliminary composite overlay on scale-stable 7.5 minute orthophoto quad sheets with a Kern PG-2 stereoplotter. The PG-2 plotter allows for a very accurate transfer of the initial lines mapped on the aerial photographs to the base map. Through a process of iterative scaling and parallax correction of control points on the photo model, we wera able to consistently compile lines onto the 1:24,000 base maps to within 0.5 mm of their plotted location. This degree of precision in compilation virtually eliminated line plotting errors in the mapping procedure. Any errors depicted in the maps can be traced directly back to the original delineation of the map units on the aerial photographs.

One of the most important steps in the preparation of vegetation maps at this scale is ground verification. In conjunction with the Hawai'i

Forest Bird Survey, all areas we mapped were ground-checked along a series of transects established through each of the study areas (Fig. 3). For most of the areas surveyed, the transects were spaced 3.2 km apart and oriented perpendicular to the elevational contours. In some of the study areas, the transects were 1.6 km apart. Along each transect, sampling stations were established at 134 m intervals. At each station, various types of data were recorded, including bird population counts and detailed information on the structure and composition of the vegetation. Information was also recorded on the phenology of selected tree and shrub species, and on the presence and impact of large feral mammals (principally pigs, goats, sheep, axis deer, and cattle) (Scott, Jacobi, and Ramsey 1981).

During the Hawai'i Forest Bird Survey, over 4,200 km^2 of area was surveyed at 9,600 stations located along 1,300 km of transect. In addition, through the 'Ohi'a Forest Study, 63, 20 X 20 m relevés were established throughout the windward forests on the island of Hawai'i, in which more detailed data on the plant communities were collected.

We also noted the location of individual sampling stations on areial photographs carried in the field. For each transect, we were able to at least locate its start and end positions, and could usually identify points where other significant landmark features, such as roads, streams, or ridges, were crossed.

Our field survey was augmented by an aerial reconnaissance of each study area to review questionable vegetation patterns identified on the air photos and to check areas between transects that were not adequately sampled along our transect grid. For example, nearly 10 hours were spent in a fixed-wing aircraft, and 15 hours in a helicopter, to conduct the aerial reconnaissance for the island of Hawai'i. The helicopter was particularly useful for obtaining close-up views of the vegetation from tree-top level.

The field and aerial survey data were combined with the vegetation patterns compiled from the aerial photographs to update the map boundaries and complete the final labeling of the map units. This last step in the mapping process also included determining the area of each mapped vegetation unit with a digital planimeter.

DESCRIPTION OF THE VEGETATION TYPE SYMBOLS

Six different types of information are coded for each vegetation type symbol: 1) tree canopy crown cover, 2) tree canopy height, 3)dominant tree species composition, 4) species association type, 5) dominant understory species composition, and 6) other information pertinent to the map unit (Table 1). The information for each map symbol is presented with a consistent format: information referring to the tree component is always listed first; species association type and understory composition are given next, enclosed in parentheses and separated by a colon; and finally, a symbol element for other information relating to the unit may be coded after the parentheses. For treeless vegetation types, the symbol elements pertaining to tree crown cover, height, and species composition are omitted.

Tree canopy crown cover. Crown cover is defined as the vertical projection of a tree's foliage cover on the ground, expressed as a percentage of a reference area. This definition assumes a relatively homogenous distribution of the foliage within the crown without taking into account crown thickness or foliage layering.

Four canopy classes are recognized on the maps: CLOSED or OPEN canopy, and SCATTERED or VERY SCATTERED trees. The definition of closed canopy used (>60%) coincides with Mueller-Dombois and Fosberg's (1974) closed forest unit. This cover class can be easily recognized in the field or on aerial photographs because most of the tree crowns interlock. The cover class for an open tree canopy is 25 - 60%. This category generally corresponds to the traditional definition of a woodland (Mueller-Dombois and Ellenberg 1974).

For tree cover less than 25%, two categories are recognized: scattered trees (5-25% cover) and very scattered trees (<5% cover). This latter category was maintained because of the importance of very scattered trees to certain bird populations.

Tree canopy height. Tree height is divided into three classes, SCRUB TREES, which are 2-5 m tall; LOW TREES, 5 - 10 m tall; and TALL TREES, greater than 10 m tall. Rarely do the native Hawaiian trees grow taller than 25 m.

Tree species composition. Species name abbreviations for all tree species composing greater than 25% of the total crown cover are listed in the map symbol. If a species does not attain this cover limit, it may be combined with other tree species and listed with a tree species association symbol (xt or nt). Introduced tree species are always combined and indicated by the "xt" symbol, regardless of their canopy cover.

In most of the symbols, more than one tree symbol element is coded, separated either by a dash or a comma. A dash indicates a co-dominance of the adjacent species name symbols, whereas a comma means that the species name or association coded first is dominant. Also, for symbols with more than one tree element, a tree height symbol may be coded for each element if they are in different tree layers or coded only for the first element if all the other symbol elements are in the same layer.

Species association type is used to indicate the species composition for any coded native tree or understory plant association symbol. For example, the native tree association symbol (nt) in a dry area (D:) is composed of one group of species, whereas in a moist or wet habitat, another group of native tree species predominates. This also applies to other life form associations such as native shrubs (ns), native ferns (nf), treeferns (tf), and mixed grasses (mg).

Understory species composition is usually coded with only species association symbols. If more than one symbol element is coded for the understory, they are separated by either a dash or a comma to indicate co-dominance or dominance. The bare ground symbol (xx) is coded if the understory vegetation covers less than 75% of the area.

Other information. Elements in this category may be used to provide additional information on a particular vegetation unit. This information may further define the characteristics of that unit, such as when the element "pio" is used to indicate a pioneer or early seral stage, or may provide additional information on the condition of the unit: sng = numerous dead or dying trees present, bur = recently burned, clr = recently cleared, and fum = recently defoliated by volcanic fume.

CONCLUSIONS

The anticipated final products of this project will be vegetation maps at two scales: 1) our most detailed maps at 1:24,000, and 2) a more generalized vegetation type map for each island at 1:100,000. This second group of maps will be produced by combining the detailed map units using a hierarchical classification scheme that will result in map units such as wet Metrosideros forest with a native shrub and treefern understory.

For the island of Hawai'i alone we have over 350 detailed vegetation units identified, of which approximately 150 constitute 95% of the total area mapped. When these units are generalized to the next mapping level, they are reduced to about 100 units, of which only 40 make up 95% of the total area.

It is anticipated that all of the primary mapping for this project will be completed by mid-1983. At that time efforts will be directed to compiling and publishing the 1:100,000-scale maps. We are optimistic that this new detailed vegetation map base will allow us to more rationally approach the identification, management, and preservation of significant representative portions of our remaining native biological resources in Hawai'i.

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TABLE 1. Elements which can be coded for each vegetation symbol component.

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          1 2     3  4    5   6
EXAMPLE:  \ |_____/  |  __/_  /
           o3Me,2nt(W:tf,ns)sng
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1. TREE CANOPY CROWN COVER

c = closed canopy, most crowns interlocking	>60% cover
o = open canopy, some or no interlocking crowns	25-60% cover
s = scattered trees	5-25% cover
vs = very scattered trees	<5% cover

2. TREE CANOPY HEIGHT

1 = low scrub trees, monopodial	2-5m tall
2 = scrub trees, moderate stature	5-10m tall
3 = tall stature trees	>10m tall

3. TREE SPECIES COMPOSITION

a) Species name or association abbreviations

Ac = *Acacia koa* (koa)
Al = *Aleurites moluccana* (kukui)
Ep = *Euphorbia* sp. (ʻakoko)
Me = *Metrosideros polymorpha*
Mr = *Myrica faya* (Firetree)
My = *Myoporum sandwicensis* (naio)
nt = native tree association
Psc = *Psidium cattleianum* (strawberry guava, waiawi)
Sa = *Sapindus saponaria* (Manele; soapberry)
So = *Sophora chrysophylla* (mamane)
xt = introduced tree association

b) Species dominance

Species composition:*	Relative Dominance:
A	only A present
A-B	A and B codominant
A,B	A dominant, B subdominant
A,B-C	A dominant, B and C subdominant
A-B,C	A and B codominant, C subdominant
A-B-C	A,B,C codominant

*Substitute the appropriate species name or association abbreviation for the letters A, B, or C.

4. SPECIES ASSOCIATION TYPE

D = Dry habitat species
M = Mesic habitat species
W = Wet habitat species

5. UNDERSTORY SPECIES COMPOSITION

a) Species name or association abbreviation (Note: Species name abbreviations for trees may also be used if the understory is dominated by individuals of that species, less than 2m tall).

bg = structured bog
mf= matted ferns, Dicranopteris spp., Hicriopteris sp., Sticherous sp.
mg = mixed native-introduced grasses, sedges, or rushes
ng = native grasses
ns = native shrubs
Pm = Passiflora mollisima (banana poka)
tf = treeferns, Cibotium spp. (hapu´u)
xg = introduced grasses, sedges or rushes
xs = introduced shrubs
xx = bare ground (at least 25% of the area)

b) Species dominance (use same format as for tree species)

6. OTHER INFORMATION

bur = recently burned
clr = recently cleared or logged
fum = volcanic fume defoliation
msc = miscellaneous unit - mix of native and introduced species in low elevation areas
pio = pioneer vegetation, seral stage on recent lava flow
sng = many standing dead or defoliated trees

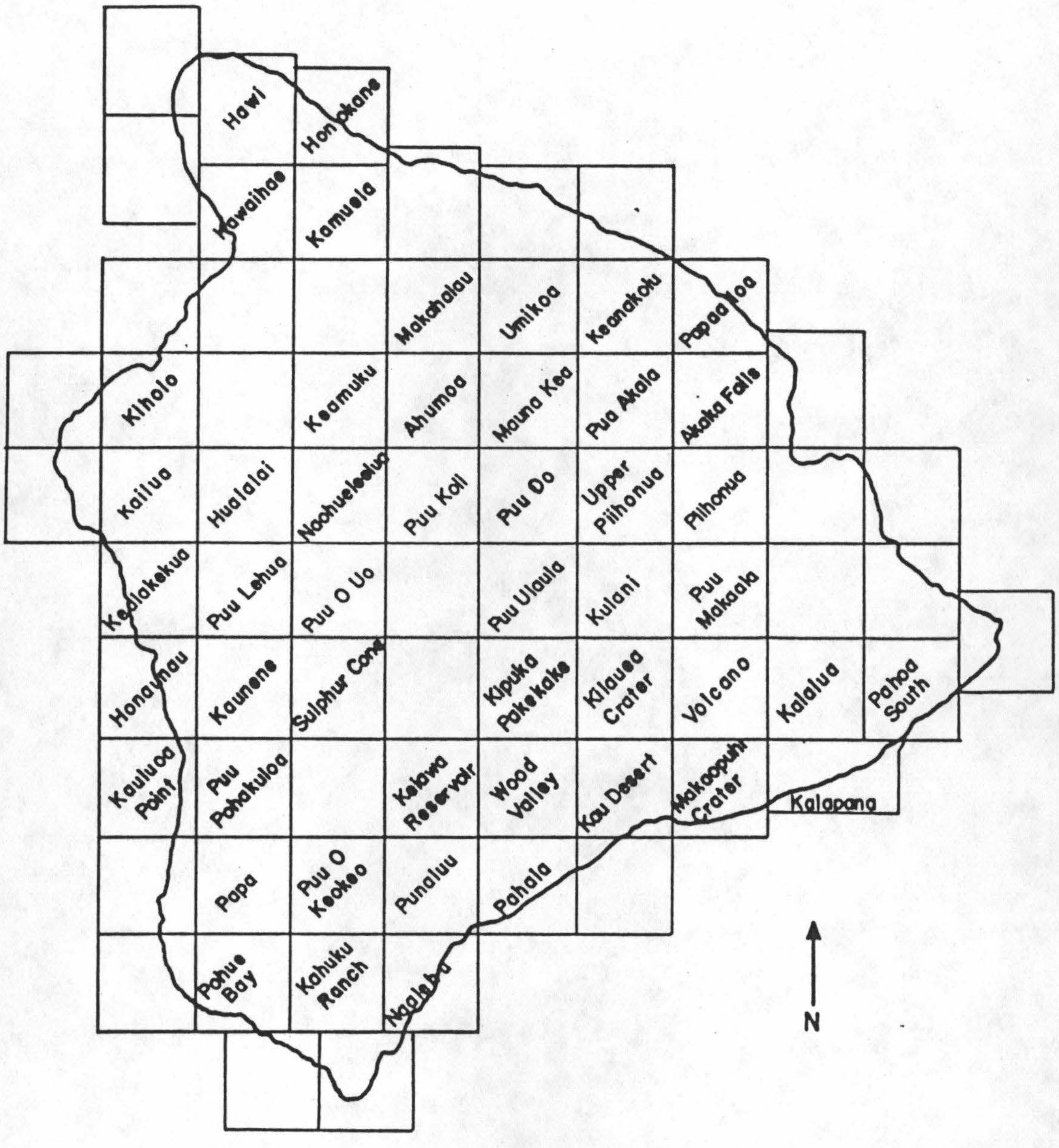


FIGURE 1. Map of the island of Hawai'i showing the 7.5 min. U.S. Geological Survey quadrangle maps with vegetation type overlays.

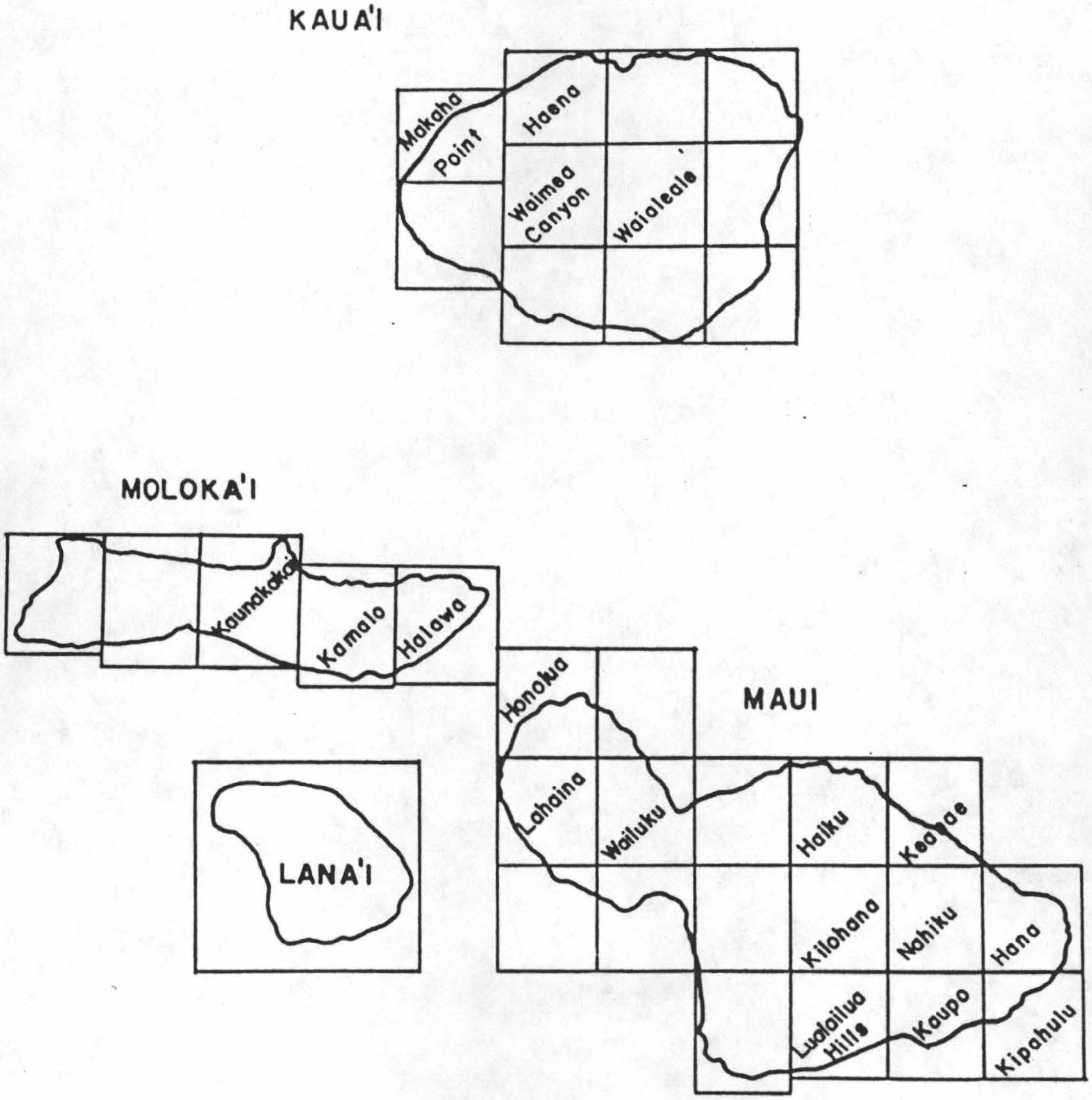


FIGURE 2. Maps of the islands of Kaua'i, Moloka'i, Lana'i, and Maui showing the 7.5 min. U.S. Geological Survey quadrangle maps with vegetation type overlays.

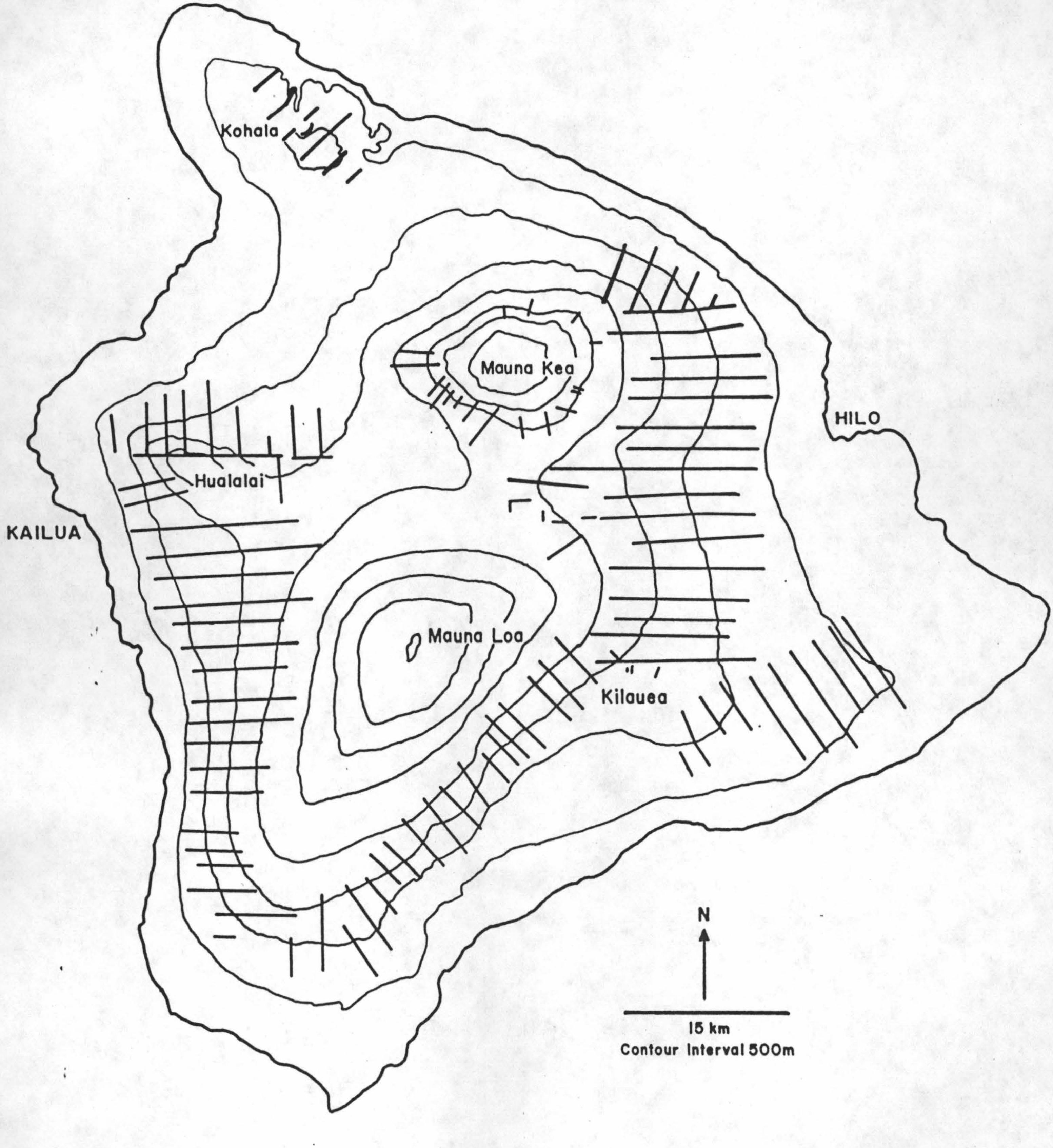
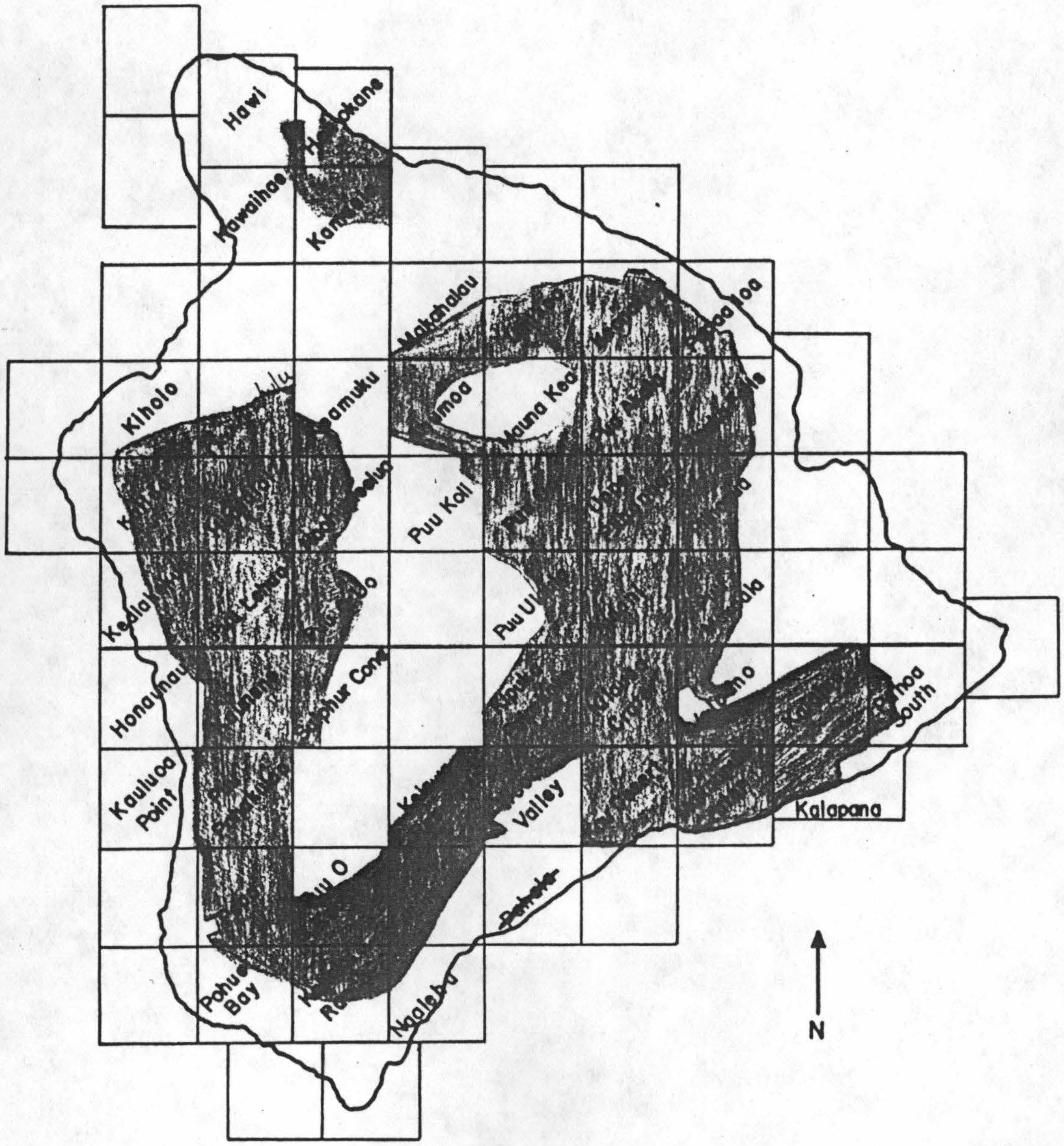


FIGURE 3. Map of the island of Hawai'i showing the location of sampling transects established during the Hawai'i Forest Bird Survey.


Hawi
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Makahalau
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Puu Kali
Puu Ulu
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Honaunau
Kauluoa Point
Valley
Kalapana
Pohue Bay
Naalehu
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